Glass and Ceramics, Vol. 68, Nos. 5 – 6, September, 2011 (Russian Original, Nos. 5 – 6, May – June, 2011)

AT ENTERPRISES AND INSTITUTES

UDC 666.199

FABRICATION OF CAST STONE ART AND ARCHITECTURAL-DECORATIVE ARTICLES

A. M. Ignatova,[1,3] M. M. Chernykh,[1] and M. N. Ignatov[2]

Translated from *Steklo i Keramika*, No. 6, pp. 31 – 35, June, 2011.

The importance of using cast stone in a new way, specifically, as a substitute for natural material (marble, granite) for making art objects, such as bas-relief, decorative architectural elements of buildings, office and garden–park sculptures, and so on, is examined.

Key words: cast stone, architecture, building materials, replacement for natural stone.

Cast stone as a material is a product of melting rocks or their basic or ultrabasic technogenic wastes. As a technology, stone casting is a process of obtaining casts from liquid, nonmetallic, multicomponent, oxide melt.

The range of application of cast stone is still very limited. Because of the high abrasion and corrosion resistance it is used as a building material for technical structures and connections, subjected to intense wear and chemical action. Out investigations have shown that cast stone also possesses a number of aesthetic properties, which in combination with mechanical and physical characteristics make it possible to use is as a substitute for natural rock. However, the currently existing technological process for obtaining cast stone does not permit obtaining complexly shaped decorative and artistic articles with diverse relief [1].

Viewing cast stone as an alternative to natural stone the fact that these materials have very similar natures must be taken into account, since the raw materials for obtaining cast stone are natural rocks. As a result of melting, many physico-technical properties of cast stone appreciably increase relative to the initial properties of the raw material, and for this reason the cast stone material obtained on the basis of ordinary stone raw material can compete with respect to technical properties with rare and expensive rocks. Table 1 gives the chemical composition of raw materials components for stone casting, Table 2 the chemical composition of some types of finished cast stone, and Table 3 the ratios of the mix components for obtaining abrasion-resistant cast-stone articles, and Table 4 a comparative analysis of the main properties of cast and natural stone [2].

The possibilities for making production runs of complexly shaped articles as well as increasing the automation level of the technological processes in the production of cast stone are much greater than for any modern stone-processing technologies since it is based not on the mechanical working of the solid material but rather on processing the melt. Castings can be obtained using different repeated-use (metal and graphite permanent molds) and one-time use (sand-clay and ceramic) molds. The simplest to implement and at the same time making it possible to obtain complexly shaped articles is casting in sand-clay molds (Fig. 1). Casting models can be made of different materials; the technology for fabricating them is no different from similar models used in metallurgy (Fig. 1). It should be noted that stone melts characterize high viscosities, 3-fold greater than the analogous indicators for cast iron. This makes it much more difficult to obtain articles with complex or fine relief, since the high viscosity results in lower fluidity and hence small depressions in the cavity of the mold are not filled as well. Viscosity control is difficult and limited by the nature of the melt itself, so that a high degree of reproducibility of the relief can be achieved by controlling the quality of the mold. Thus, two types of mold mixes are recommended for fabricating sand-clay molds for producing artistic articles — facing and filling. A facing molding mix is used to make the working layer of the mold while a filling mix is used to fill the mold after a facing mixture is deposited on the model.

[1] Izhevsk State Technical University, Izhevsk, Russia.
[2] Perm State Technical University, Perm, Russia.
[3] E-mail: ignatovaanna2007@rambler.ru.

TABLE 1. Chemical Composition of Mix Components for Obtaining Cast Stone

Content, wt.%	Mix component, %																
	SiO_2	CaF_2	Al_2O_3	CaO	FeO	MgO	Fe_2O_3	TiO_2	$K_2O + Na_2O$	Cr_2O_3	MnO	V_2O_5	S	P_2O_5	B_2O_3	NaF + KF	other
Hornblendite	37.0	–	13.0	8.3	5.8	10.8	8.9	1.1	1.7	–	–	–	–	–	–	–	13.4
Basalt	45.5	–	15.0	11.5	9.1	11.0	2.5	1.0	2.4	–	–	–	–	–	–	–	2.0
Chromite rock	6.9	–	–	1.2	4.7	14.5	9.7	–	–	45.0	–	–	–	–	–	–	18.0
Quartz sand	95.0	–	2.0	0.3	1.3	0.9	0.5	–	–	–	–	–	–	–	–	–	–
Regenerated molding mix	90.0	–	2.5	1.8	2.2	2.0	0.8	–	–	–	–	–	–	–	–	–	0.7
Fluorspar	–	93.0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	7.0
Furnace slag	25.0	–	15.5	31.0	2.0	12.5	–	9.0	–	–	0.5	0.2	4.3	–	–	–	–
Slip wastes from enamel production	43.0	–	4.2	5.5	–	0.7	–	8.3	13.5	–	–	–	–	1.8	13.6	2.2	7.2
Fluorine-containing sludge	10.0	69.0	3.5	3.6	–	2.8	–	–	1.8	–	–	–	–	–	–	–	9.3

TABLE 2. Chemical Composition of Some Forms of Finished Cast Stone

Type of casting	Content, wt.%								
	SiO_2	TiO_2	Al_2O_3	MgO	CaO	$K_2O + Na_2O$	FeO	Fe_2O_3	Cr_2O_3
Abrasion-resistant	47.3	2.3	12.5	8.3	9.5	2.1	10.9	3.4	0.5
Chemically stable	45.5	1.7	15.0	12.0	11.5	2.4	9.1	3.5	–

TABLE 3. Composition and Ratio of Mix Additives for Obtaining Abrasion-Resistance Cast Stone

Material	Content in mix, wt.%	Chemical composition, %									
		SiO_2	CaF_2	Al_2O_3	CaO	FeO	MgO	Fe_2O_3	TiO_2	$K_2O + Na_2O$	Cr_2O_3
Hornblendite	88	37.0	–	13.0	8.3	5.8	10.8	8.9	1.1	1.7	–
Chromite stone	3	6 – 7	–	–	0.8 – 1.2	4 – 6	14.5 – 15.5	8 – 15	–	–	30 – 32
Quartz	2	91 – 97	–	2 – 4	0.2 – 0.6	1 – 2	0.8 – 1.2	0.3 – 0.5	–	–	–
Molding mix	5	82 – 92	–	2 – 8	0.5 – 2.5	2 – 3	1.0 – 2.5	0.5 – 1	–	–	–
Fluorspar	2	–	61 – 92	–	1 – 2	–	–	–	1 – 2	–	1 – 2

A particular feature of the production of cast stones is that in most cases the melt must be poured into casting molds heated to 550 – 750°C to prevent vitrification of the casts. This must be taken into account when fabricating models for cast stones. In spite of the linear shrinkage of the cast stone, fluctuating from 1.3 to 2.3%, the dimensions of the finished articles are greater than those of their models. This occurs largely because the molds expand when heated. All together the difference between the models and the finished articles is small and equal to 0.5 – 0.6%.

Hornblendite was melted in a two-electrode arc furnace with dinas lining, working voltage 220 V, and working current 700 – 800 A. The current was regulated by the submersion depth of the graphite electrodes in the melt. The melt obtained in this manner has two layers in the furnace: 1) top — foamy, hottest and 2) bottom — more uniform, somewhat cooler. As the melting process went to completion, the bottom (main) layer of the melt became increasingly cooler, more homogenized, and degassed. The medium in the furnace tank was reducing on account of the graphite electrodes, which promoted the reduction of iron and silicon from the mix with formation of ferrosilicon, which precipitated on the bottom of the tank. The metallic melt was poured off as soon as the furnace gate was opened, after which the stone melt was poured into an unlined metal ladle, whose interior surface was prepared beforehand and heated to 600 – 900°C. During pouring the ladle was filled to the 3/4 level, after which the melt was allowed to degas for 3 – 4 min. The tem-

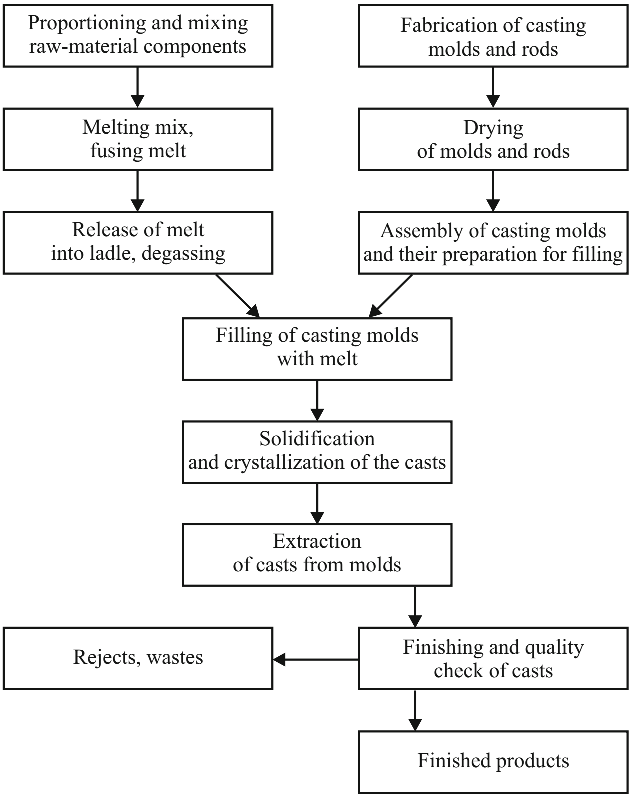

Fig. 1. Technological scheme for fabricating cast stone by casting in sand-clay molds.

perature of the stone melt at release from the furnace into the ladle was 1500 – 1520°C.

The stone melt was poured into the cavity of the casting mold from an unlined metal ladle on a pouring square. Special attention was devoted to the uniformity and height of the melt stream, whose should not exceed 25 cm otherwise the stream starts to twist, trapping air which can result in different kinds of defects. The temperature of the stone melt when poured into the mold was 1250 – 1320°C.

The most important and critical stage of the technological process of fabricating cast stone is the process of forming a uniform pyroxene structure in it. This was accomplished by crystallization-firing treatment. The filled molds are placed in a 38-m long electric crystallization-firing tunnel furnace (power 220 kW). After a heat-treatment cycle was completed, the castings were removed from the molds and carefully cleaned of the residues of the molding mix. Next, the castings were subjected to finishing operations.

The most important question of the cast-stone technology and, especially, the possibility of obtaining artistic articles by means of this technology is the quality of the relief being reproduced. This parameter can be determined most objectively by using a simple numerical method developed by the present authors [3].

The method consists in comparing images of the model and casting and calculating the agreement between them. The EpsonPerfection 1270 graphics scanner was used to obtain high-quality images of the surface relief of the models and the castings prepared from them.

Before making a comparison the images of the models and castings were subjected to additional processing with AdobePhotoshop, converting them to a black-white format. This operation is necessary in order to obtain objective results from a comparison made using the program ImageCompare 3.5. This program was chosen because the results of a comparison of two images, namely, the degree to which the two images are identical to one another, are given by the program in percent, i.e., directly in the form in which they can be used without any additional mathematical calculations.

The results obtained were used to determine the dependence of the degree of reproducibility of the relief on its geometric size; a geometric image of the relief is shown in Fig. 2. Thus, it was established that when preparing castings from cast stone in one-time sand molds the optimal minimal size of the image details of portrait plastic art made of cast stone is 3 – 4 mm. Smaller details are reproduced inaccurately, no better than 60%.

The relations between the reproducibility of a relief and its size are valid not only for bas-relief but also for three-dimensional articles, for example, small plastic art objects.

TABLE 4. Physico-Mechanical and Chemical Properties of Cast Stone and Some Natural Rocks

Indicator	Cast stone		Marble	Granite	Labradorite
	hornblendite	dolomite			
Density, kg/m^3	2900 – 3000	2800 – 2900	2700	2600	2700 – 2800
Water absorption, %	0.13	0.7	0.2	0.4	0.5 – 0.2
Compression strength, MPa	250 – 500	100 – 260	74	148	160 – 450
Bending strength, MPa	30 – 50	10 – 30	–	–	–
Impact toughness, kJ/m^2	1.25	1.06	1	0.5	0.4
Heat resistance, °C	150	700	–	–	–
Thermal conductivity, W/(m · K)	1.52	1.07	–	–	–
Abradability, g/m^2	1	1.4	1.8	1.3	4 – 7
Acid-resistance, %	97	92	95	94	88

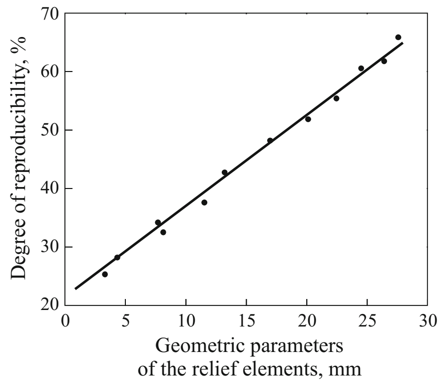

Fig. 2. Degree of reproducibility of the relief of cast stone castings obtained using one-time sand-clay molds as a function of its geometric dimensions.

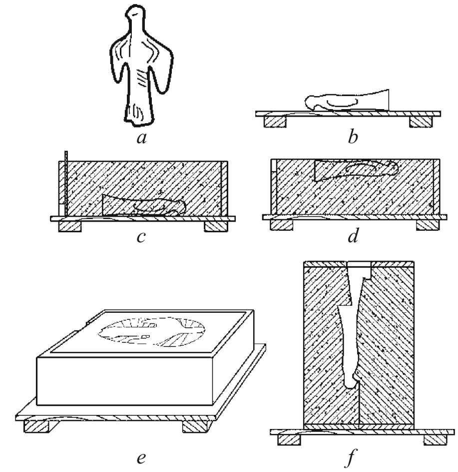

Fig. 3. Diagram of modeling with cutting: *a*) model; *b*) model placed on a submodel plate; *c*) bottom half-mold; *d*) inverted bottom half-mold without cutting; *e*) bottom half-mold with designed shaped parting surface; *f*) assembled mold.

However, the technology for making molds for obtaining such articles becomes complicated, and it is recommended that the method of molding with cutting be used. An example of this method is a figurine made in an ethnic style. The cuts in the molding mixture were made in the form of depressions with flat walls so that the mixture could be freely removed from them in the form of "dummies" when the mold was disassembled. Thus, the shaped disassembly surface of the mold corresponded to the edge relief of the model and did not interfere with the free removal of the model from the bottom half-mold (Fig. 3).

To determine the extent to which cast stones are competitive with respect to similar articles made of natural stone, their decorativeness must be evaluated.

Decorativeness can be evaluated in the following sequence: determine the polishability; evaluate the decorativeness (neglecting indicators that have a negative effect on the decorativeness); taking account of the correcting (negative) indicators affecting decorativeness; establish the decorativeness class; formulation of an expert conclusion on decorativeness [4].

Methods for evaluating decorativeness are presented in GOST 896–98, according to which the cast stone is assigned to category I of polishability with degree of polishability 200.

The evaluation of decorativeness of cast stone includes an evaluation of the texture, determination of the category of the structure, translucency, and color.

The texture of the cast stone was evaluated according to the degree of development of the figure. Polished prefabricated samples were used for this purpose as well as to evaluate the development of the structure. Two types of figures are characteristic of cast stone: uniform figure — uniform coloration, striped figure — figure consisting of several black and light-grey bands. Depending on the trajectory of the melt stream, a straight-stripe or wavy-stripe figure is formed. In accordance with these indicators, according to GOST 30629–99, cast stone with a uniform figure is placed in category II while cast stone with a striped figure is placed in category I.

Conventionally, three types of structures are identified: glassy, cryptograiny, and grainy. A difficulty arises in evaluating cast stone, since any of the structures mentioned can be attained, theoretically, in cast stone by changing the technological parameters. However, the most common cast-stone structure is glassy, corresponding to the grainy-glassy group; sections with cryptograiny structure are also encountered in cast stone. According to GOST 30629–99 the structure of cast stone corresponds to category II.

The translucency was evaluated from the capability of cast stone to transmit light through the top layer, revealing the inner figure and structure. According to GOST 30629–99 cast stone is assigned to category III, since no translucency was found.

According to GOST 30629–99 the color of cast stone can be characterized by the color tone, degree of saturation, and brightness. All colors perceived by humans are divided into chromatic (I) and achromatic (II). Chromatic colors include yellow, red, light blue as well as composite colors obtained by combining two of three basic colors: orange, violet, and green. The achromatic colors are black, black-grey, dark-grey, medium-grey, light-grey, white-grey, and white, differing from one another by the degree of brightness. The color range of cast stone refers to achromatic colors, so that its degree of saturation was not determined.

The brightness indicator was established according to the intensity of the reflection of light by a surface. The brightness of cast stone was measured with a photoelectric brightness meter of the type FB-2 according to GOST 896–98. According to GOST 30629–99 cast stone corresponds to the second brightness step and brightness category I. The brightness of cast stone can be different depending on the chemical composition.

In evaluating color, color preference (uniqueness), uniformity, play of the tones of the main color, and the combina-

TABLE 5. Data on the Decorativeness of Cast Stone

Main decorativeness indicator	Positive decorativeness indicator	Indicator category	Indicator characteristic	Evaluation, scale units
Color	Chromaticity	II	Achromatic	2
	Saturation	–	–	–
	Brightness	I, II, III	Black and grey tone	2
	Color preference	III	Common	2
	Uniformity	I	Uniform tone	4
	Color combination	I, II	Polychromic and monochromic	4
Texture	Figure	I, II	Layered and no figure	4.5
	Structure	II	Medium-grainy	2
	Translucency	III	Not translucent	1
Execution	Polishability	I	Above 160 units	5

Fig. 4. Architectural and building articles made from cast stone: *a*) basaltic slab; *b*, *c*) hornblendite rosette; *d*) hornblendite slab with decorative figure.

tion of colors were also taken into account. The dominant color in cast stone is black or dark-grey; according to GOST 30629–99 cast stone corresponds to category III.

With respect to color uniformity cast stone is divided into two categories: uniform and nonuniform. With respect to the combination of colors cast stone can be put into the following categories: polychromic with a favorable combination of colors within the nuance of the harmonies; monochromatic with harmonious deviation from the dominant color.

After the decorativeness of cast stone was established, the preliminary evaluation of the decorativeness made neglecting the indicators having a negative effect on decorativeness was checked and the total evaluation made according to each decorativeness indicator was refined by introducing the corresponding correction factors from GOST 30629–99, which take account of the effect of negative indicators on a given decorativeness indicator. All data used to calculate the decorativeness of cast stone are summarized in Table 5.

To establish the decorativeness class of the cast stone the final arithmetic-mean value of the decorativeness was compared with the classification of the decorativeness of stone facing materials, which is presented in GOST 9479–98. It was determined that cast stone corresponds to category II, which is evaluated as decorativeness. Classification in this category shows that cast stones are highly competitive.

The fact that the articles can be made in large runs shows that the list of decorative and artistic articles can include tiles, rosettes, and other architectural-decorative articles (Fig. 4).

In summary, cast stones as a material can be a full alternative to nature stone not only with respect to operational properties but also decorativeness. Cast stone technology makes it possible to achieve high output, large number of copies, and high level of automation using mineral raw materials that are not in short supply.

REFERENCES

1. A. M. Ignatova and M. M. Chernykh, "Cast stone in fabrication of decorative articles and architectural-artistic elements," in: *Proc. 5th Intern. Conf. on Mining, Construction, and Energy* [in Russian], Tula (2009), pp. 19 – 27.
2. A. M. Ignatova and M. M. Chernykh, "Cast stone — effective method of making artistic articles," in: *Artistic Materials Science: Natural Stone, Design, Technology* [in Russian], MGGU, Moscow (2010), pp. 343 – 353.
3. A. M. Ignatova, M. M. Chernykh, A. A. Kutergin, and M. M. Kaminskii, "Use of cast stone for making portrait bas-relief and high relief," *Dizain*, *Mater., Tekhnol.*, No. 1, 27 – 32 (2010).
4. A. M. Ignatova, M. M. Chernykh, V. L. Popov, and M. M. Kaminskii, "Aesthetics and technology of making cast stone tiles," *Dizain*, *Mater., Tekhnol.*, No. 2, 37 – 44 (2010).
5. A. M. Ignatova and M. M. Chernykh, "Evaluation of the suitability of cast stone for making decorative and architectural-artistic articles," in: *Proc. 12th All-Russia Scientific-Applications Conference on Technology of Artistic Treatment of Materials* [in Russian], RGSU, Rostov-na-Donu (2009), pp. 32 – 49.